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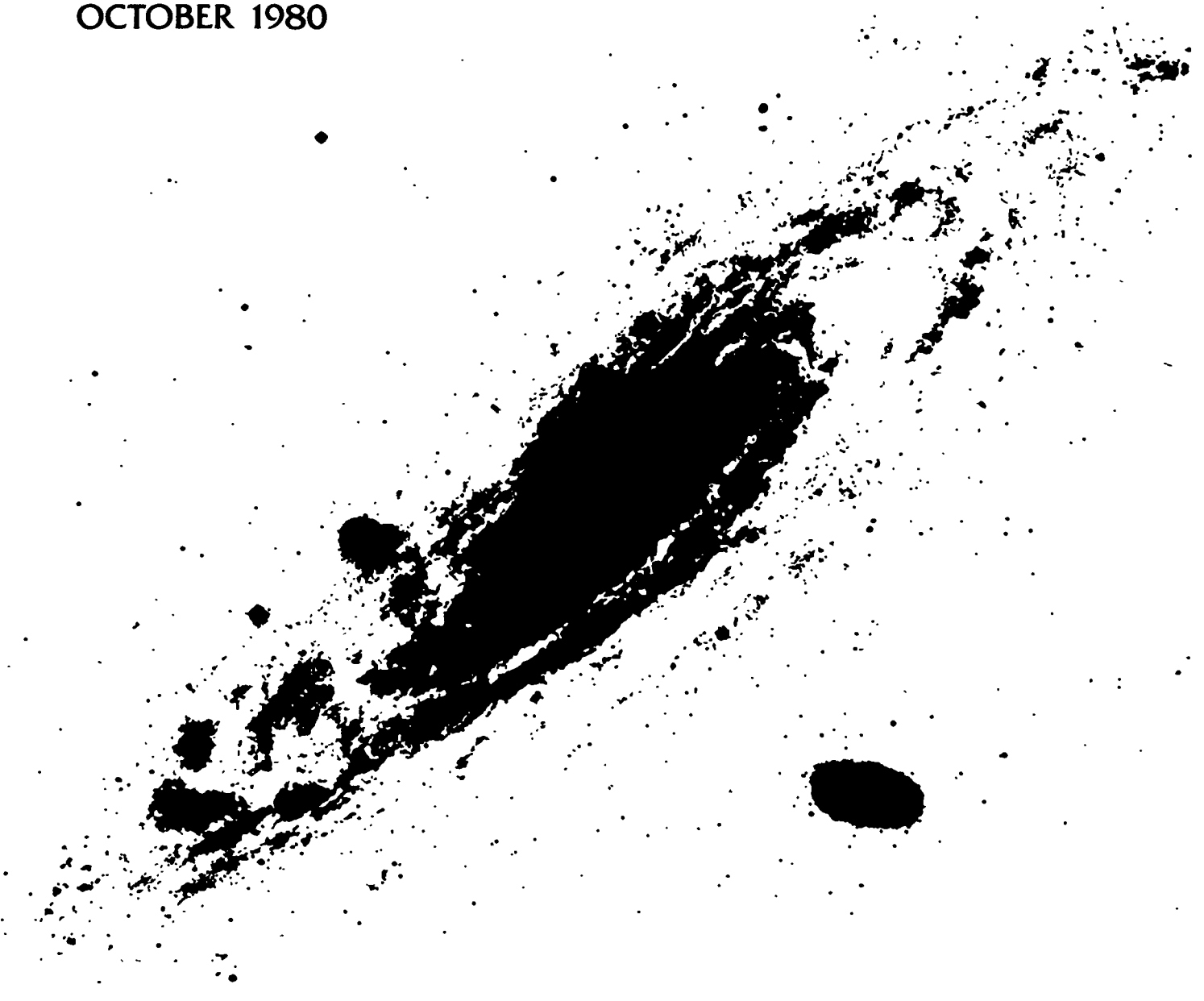
ASTROPHYSICS NEAR-TERM PROGRAM

PROJECT CONCEPT SUMMARY:

Cosmic Ray Observatory (CRO)

OCTOBER 1980



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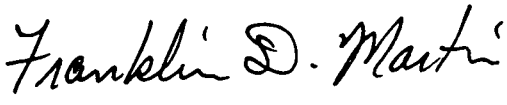
FOREWORD

This document is one in a series describing projects of current interest in NASA astrophysics planning. Some of these projects were originally suggested by the Space Science Board of the National Academy of Sciences and the Outlook for Space Study Group. Others have been suggested by various internal working groups. Still others have been suggested by individual scientists or scientific groups both within NASA and in the broad astrophysics community. The descriptions presented in these volumes are based on technical studies or preliminary assessments done by NASA's Ames Research Center, Goddard Space Flight Center, Marshall Space Flight Center, and the Jet Propulsion Laboratory. Since the projects are at various stages in the planning process, the level of detail presented gives our current best estimate of the scientific objectives and technical characteristics. Where variations such as alternative strawman payload combinations have been studied, these are presented, and their effects on the overall project are discussed. Specific spacecraft, and other systems or subsystems, are identified or implied in many cases to illustrate that a concept for conducting the project exists. Such identification does not reflect a commitment on the part of NASA to utilize such hardware should the project be implemented. Similarly, in the actual implementation of any particular project, details will inevitably change. Our objective in assembling these documents has been to produce a set of concise project descriptions in a uniform format. They are intended to serve as a basis for discussion within the astrophysics community and to help determine how individual missions can best be accommodated within NASA's overall astrophysics program.

This document was prepared by Dr. Jonathan Ormes (Study Scientist) and William Hibbard (Study Manager) of the Goddard Space Flight Center.



Franklin D. Martin
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Office of Space Science

COSMIC RAY OBSERVATORY (CRO)

PROGRAM SUMMARY: Part of High Energy Observatory Series
Multiple Experiment Payload
Spacecraft Bus

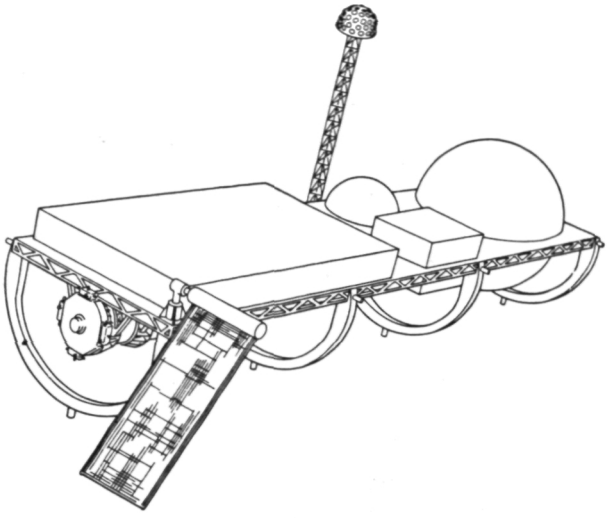
LAUNCH DATE: Approximately 4 years after program start

MISSION LIFETIME: 2 years

MASS ESTIMATE: Spacecraft: 3,000 kg
Instruments: 15,000 kg

FINAL ORBIT: Altitude: 400 km circular
Inclination: 56°

LAUNCH VEHICLE: KSC Shuttle



OBJECTIVES:

The CRO mission is designed to allow the study of the origin of the elements and to learn about the nucleosynthetic processes that produce the cosmic ray nuclei. It will permit the study of the acceleration of particles in astrophysical environments, such as supernova remnants, the interstellar medium, and pulsars, and will further our understanding of how cosmic rays contribute to the energy budget of the galaxy, affect the dynamics of the galaxy, and contribute to catalyzing molecule formation through their ionization loss in the interstellar medium. Finally, it will provide knowledge as to the location and types of sources that fill the galaxy with relativistic particles, will allow the study of the particles themselves at extremely high energies, and will provide an opportunity to search for exotic or as yet undiscovered particles.

INSTRUMENTS:

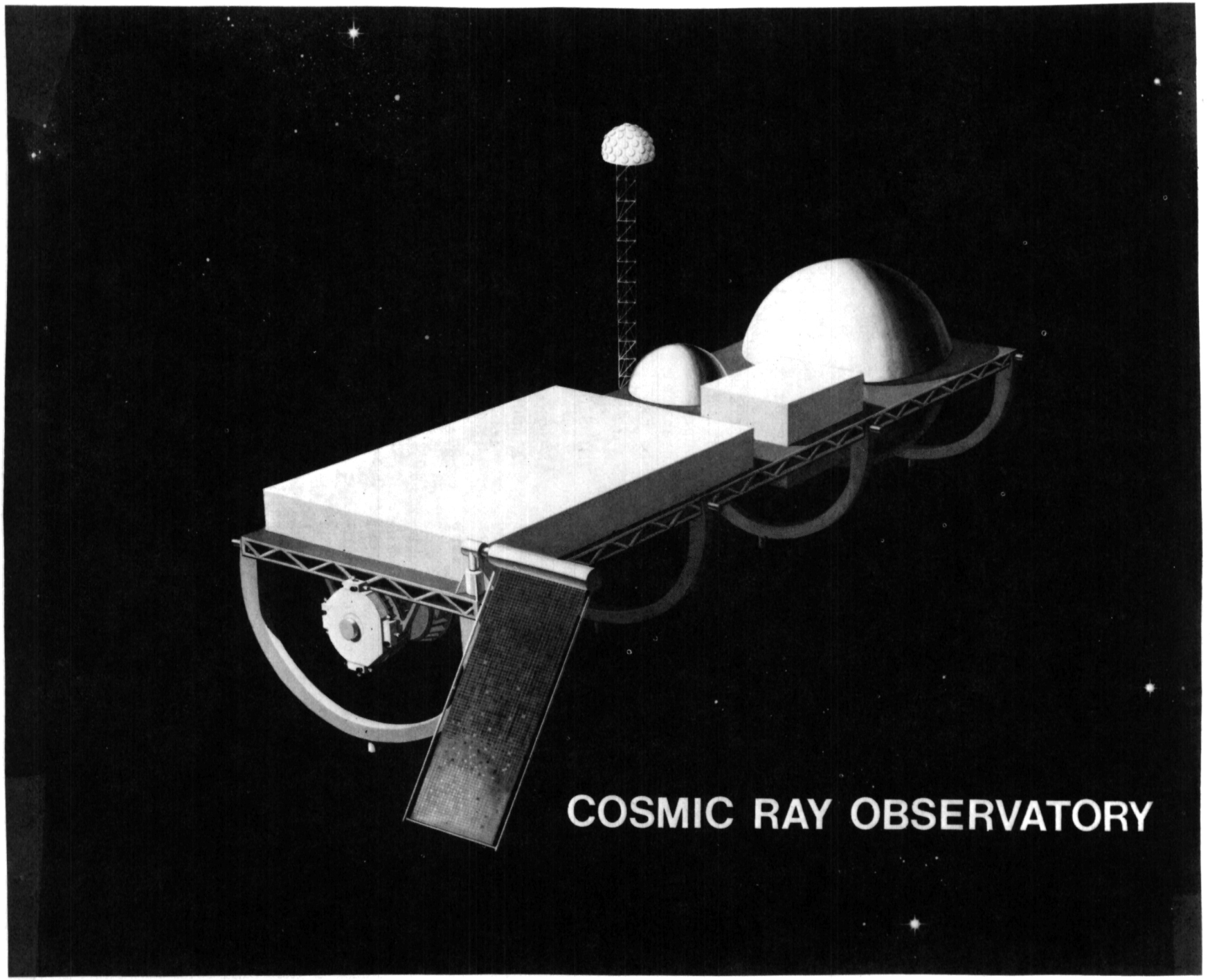
The CRO investigations will be performed using Principal Investigator (PI) class instruments. Each instrument will be a particle telescope specifically designed to look at a given species of particles. A variety of techniques, such as transition radiation detectors, ionization loss counters, Cerenkov counters, superconducting magnets, ionization calorimeters, and trajectory devices will be used.

MISSION DESCRIPTION:

The spacecraft will be inserted into a 400-km circular orbit at 56° inclination. This orbit assures a 2-year lifetime, and will go to a high enough geomagnetic latitude to accommodate the isotopic composition studies. Pointing the instruments to the local zenith (1°) will permit continuous science observations. Communications will be accomplished via the Tracking and Data Relay Satellite System (TDRSS).

STATUS:

This program is unfunded and unapproved. Experiments must be solicited and selected. Detailed studies must be performed.


COSMIC RAY OBSERVATORY

SCIENCE

Rationale

The CRO Mission will provide answers to questions regarding the origin, acceleration, and propagation of cosmic rays which have mystified astrophysicists for the past 50 years. It will provide insights into the nucleosynthesis of the elements and into the physics of particles at ultrahigh energy. The new information will complement that from radio, gamma-ray, and X-ray astronomies to provide information about the properties of the interstellar medium.

Cosmic rays have a dual role in modern astrophysics. The radiation is an important channel of astrophysical information about stars and other astronomical objects; the cosmic-ray gas itself is an astronomical object of fundamental intrinsic interest. The cosmic rays are responsible for the nonthermal radiations we observe, including synchrotron, bremsstrahlung, and inverse Compton radiations from cosmic-ray electrons and π° decay gamma rays and neutrinos from cosmic-ray nucleons.

The particles represent a unique sample of material from outside the solar system. Ranging over the whole periodic table, they bring direct evidence of processes of nucleosynthesis and particle acceleration which occur, perhaps as a direct result of explosive processes, in stars throughout our galaxy. These nuclei, particularly when considered on an isotope-by-isotope basis, provide a powerful check on theoretical ideas about element synthesis. For example, measurements of the iron and nickel isotopic composition yield direct information on the neutron excess in the nucleosynthetic environment. The isotopes of neon, magnesium, and silicon will convey important things about how the synthesis zones of massive, highly evolved stars are mixed to make cosmic rays. An early indicator of the importance of these isotopes is the recent confirmation that ^{22}Ne is anomalously high at the cosmic-ray source. The relative abundance of the actinides bears directly on questions of which types of nucleosynthetic processes, e.g., the rapid and slow neutron capture processes, are most important.

Studies of the acceleration and propagation of the particles are of fundamental intrinsic interest. Observations of radioactive nucleides provide clocks for studying relevant time scales important in understanding cosmic rays. The lifetime of particles in the source and/or propagation regions can be inferred, and limits can be put on the time between nucleosynthesis and cosmic-ray acceleration. Changes in the composition of nuclei and the spectral indices as a function of energy reflect acceleration processes and any atomic selection effects. Studies of the electronic component and its relationship to the nuclear component are also important. Electrons interact strongly with the galactic magnetic fields and photons, and contain both primary (negatron) and secondary (positron) particles. The nuclei interact strongly with ambient matter. These two separate species also allow us to probe, with the aid of synchrotron radiation and gamma rays, the relationship between matter and fields in the galaxy.

The pressure generated by the cosmic rays plays an important role in determining the structure of the galaxy, and may help to clump the gas to form clouds and stars. The ionization energy loss may be significant in heating and ionizing the interstellar gas and in catalyzing molecule formation. The combination of all these data helps us to sort out the effects due to nucleosynthesis, preferential acceleration, mixing of supernovae material with the interstellar medium, and propagation of the particles in the galaxy.

On the basis of our present knowledge of nuclear processes and our ideas about the symmetry of nature, one expects the universe to be symmetric with respect to

the distribution of matter and antimatter. Our local environment seems to consist only of matter, and the search for antimatter requires sampling of material from environments very different from our own. The discovery of even a single antinucleus in the cosmic radiation would have profound implications for cosmology. Recent balloon measurements have been able to detect antiprotons produced by cosmic-ray collisions with interstellar material.

The study of high-energy nuclear interactions, at an energy beyond that available using man-made accelerators, can be done only by studying extensive air showers in cosmic rays. These studies have suggested the existence of new phenomena which reflect the quark structure of the organization of matter and scaling-law invariance. A knowledge of the cosmic-ray intensities and composition at high energies is essential for all such studies.

Historically, the search for hitherto unknown particles has been an important aspect of cosmic-ray research. Because of the very large amount of energy available, extremely massive particles might be found in cosmic rays. The discovery of a magnetic monopole or an extremely heavy nucleus (superheavies which might exist in an island of stability at $Z \approx 120$) would be of tremendous scientific importance.

Cosmic rays include nuclei throughout the periodic table, from hydrogen at least through uranium, as well as electrons and positrons. Our current knowledge of cosmic-ray composition is quite complete for atomic numbers 1 through 28 (nickel) and energies of about 0.1 to 10 GeV/nucleon. However, only preliminary measurements have been made of nuclei heavier than nickel. Improved resolution and statistics are needed to resolve questions concerning the nucleosynthesis of the cosmic rays, the time scales between synthesis and acceleration, and the acceleration mechanisms themselves.

Objectives

The mission proposed would address the following questions:

a. What is the origin of the elements in general, and of the cosmic radiation in particular? Where are these elements synthesized? What are the mechanisms of nucleosynthesis? Are there components of the cosmic radiation, such as superheavies and monopoles, which we do not find in the Earth and are unable to synthesize in our laboratories?

b. How are the cosmic rays accelerated? How are the products of explosive nucleosynthesis and interstellar material mixed in the cosmic rays? Is the acceleration taking place in supernova explosions, in processes in supernova remnants, or in the interstellar medium? Are there preferential acceleration mechanisms which make the composition of cosmic rays different from that of other objects such as the interstellar medium or the solar system?

c. How do particles propagate in the interstellar medium? Is the galaxy open or closed to cosmic ray escape? What is the lifetime of particles in our galaxy? Is there a metagalactic component of cosmic rays? Do cosmic rays help to form clouds?

d. What are the properties of interactions at high energies? Are there new exotic particles in the cosmic radiation? What new phenomena does one encounter at energies higher than that available to us at man-made accelerators?

The free-flyer mission will dramatically expand the presently available data by extending observations to the rare components and to much higher energies. Some of the questions outlined above will be answered so that even more focussed questions can then be asked. Theoretical models will be evaluated on the basis of valid observational data and irrelevant models will be discarded.

The experimental objectives for detailed study would include:

a. The study of H and He nuclei to 10^{15} eV/nucleon, where effects of magnetic containment by the galaxy would appear.

b. The study of the composition of nuclei $3 \leq Z \leq 28$ up to 10^{13} eV/nucleon to study source models, propagation models, preferential acceleration mechanisms, etc.

c. The study of isotopes of all the nuclei in the periodic table up to Ni at energies between 0.1 and a few GeV/nucleon in order to understand the nucleosynthesis mechanisms; observations of radioactive nucleides give information on the lifetime of cosmic rays and on the time scales between synthesis and acceleration.

d. The study of electron and positron components gives information on their lifetime in the galaxy, on their production mechanisms, and on the interactions of cosmic rays with interstellar matter and magnetic fields.

e. The study of nuclei with $Z \geq 28$ (up to 10 GeV/nucleon) with resolution capable of identifying individual nuclei to understand nucleosynthesis mechanisms (explosive nucleosynthesis, r- and s-processes, He shell burning process, etc.).

f. The search for superheavy nuclei, antiprotons, and exotic particles such as monopoles, antinuclei, etc.

Typical Instrument Payload

A group of instruments, which would complement each other in ensuring that balanced results would be obtained in all areas of interest, is described. Prototypes of the instrumentation envisioned were developed originally for balloons or HEAO-3 and some of these may also fly on Spacelab missions. Exposure in space for prolonged periods of time would ensure background-free, high-statistic results for these experiments.

Detector for Nuclei of $Z \geq 30$

a. Ion chambers, Cerenkov counters, trajectory device

b. Study of $30 \leq Z \leq 100$ nuclei (200 MeV/nucleon); search for superheavies ($Z>100$) and magnetic monopoles

c. 25 to 30 m^2, wt 3000 kg, 500 bps, 120 W

d. Study abundance of individual nuclei $\sigma = 0.3$ charge units with exposure 10 times that of HEAO-C.

Transition Radiation Composition Detector

a. Scintillation, Cerenkov counters, trajectory device, and transition radiation detectors

b. Study of nuclei $6 \leq Z \leq 28$, spectra from 0.5 TeV/nucleon to 5 TeV/nucleon

c. 2 m x 2 m; wt 1000 to 2000 kg, 2 kbps, 80 W.

Ionization Calorimeter

a. Scintillation, Cerenkov counters, gas Cerenkov counter, trajectory device, and ionization spectrometer

b. Study of proton and helium spectra to 1000 TeV/nucleon and light elements up to 10 TeV/nucleon, and provide continuous energy measurement from a few x 10^9 eV/nucleon onward for all nuclei

c. 3000 to 5000 kg; 2 kbps; area of calorimeter 1 m x 1 m, 100 W.

Isotopic Composition of Nuclei $Z<30$

a. Scintillation, Cerenkov counters, and trajectory device

b. Study of the relative abundance of isotopic elements ($E>5$ GeV/nucleon)

c. 2 m x 2 m; wt 2000 kg, 2 kbps, 75 W.

Magnetic Spectrometer

a. Scintillation, Cerenkov counters, superconducting magnets, trajectory devices, and cryogenics

b. Study of electrons, positrons, protons, and antiprotons antinuclei

c. 50 cm x 50 cm, 2000 to 5000 kg, 500 bps, 200 W.

MISSION DESCRIPTION

General

The spacecraft will be inserted into a 400-km circular orbit at 56° inclination. This orbit assures a 2-year lifetime, and will go to a high enough geomagnetic latitude to accommodate the isotopic composition studies. Pointing the instruments to the local zenith (within 2°) will permit continuous observations. The expendables stored on board will provide a 2-year lifetime. Communications will be accomplished via the Tracking and Data Relay Satellite System (TDRSS) Multiple Access System. Ground operational control will be provided through GSFC POCC.

Mission Phases

The phases of the CRO mission follow:

a. Launch Phase. The CRO will be launched by the Space Shuttle from the KSC directly into the 56°-inclination, 400-km circular Shuttle orbit. Time of year or time of day of launch are not constrained by the science.

b. Deployment and Checkout. The spacecraft will be deployed from the Shuttle using the Remote Manipulator System (RMS). Systems will be fully activated and the performance of the spacecraft monitored by an Operational Control Center (OCC) via the TDRSS link. The operability of all systems will be verified prior to departure of the Shuttle.

c. On-Orbit Operations. The planned lifetime is 2 years of on-orbit operations.

d. Retrieval. Because of the large mass of the spacecraft and instruments, retrieval of the complete observatory may require two Shuttle flights in order to meet the Shuttle landing-weight limitation.

SPACECRAFT CHARACTERISTICS

General

The spacecraft will consist of the instrument module, a support module, and a propulsion module. Because of the large instrument size and weight, the instrument module will be the major structural element in the system. It will support the instruments, the support module, the solar arrays, and the antennas. CRO (Figure 1) will weigh approximately 18,000 kg.

Instrument Module

All of the science instruments will be integrated into an instrument module, using a support module simulator. The instrument module will also include local control and data handling functions that are appropriately independent of the support module functions.

Support Module

The support module is an integrated package that provides the usual support functions (attitude control, power, communications, command, data handling, etc.) for the mission. It provides all control functions for the propulsion module. The solar array and high-gain antenna are functionally a part of the support module but may be physically located on any of the three modules.

Attitude Control Subsystem (ACS). The ACS will provide Earth pointing to an accuracy of 1° rms. In addition, the ACS

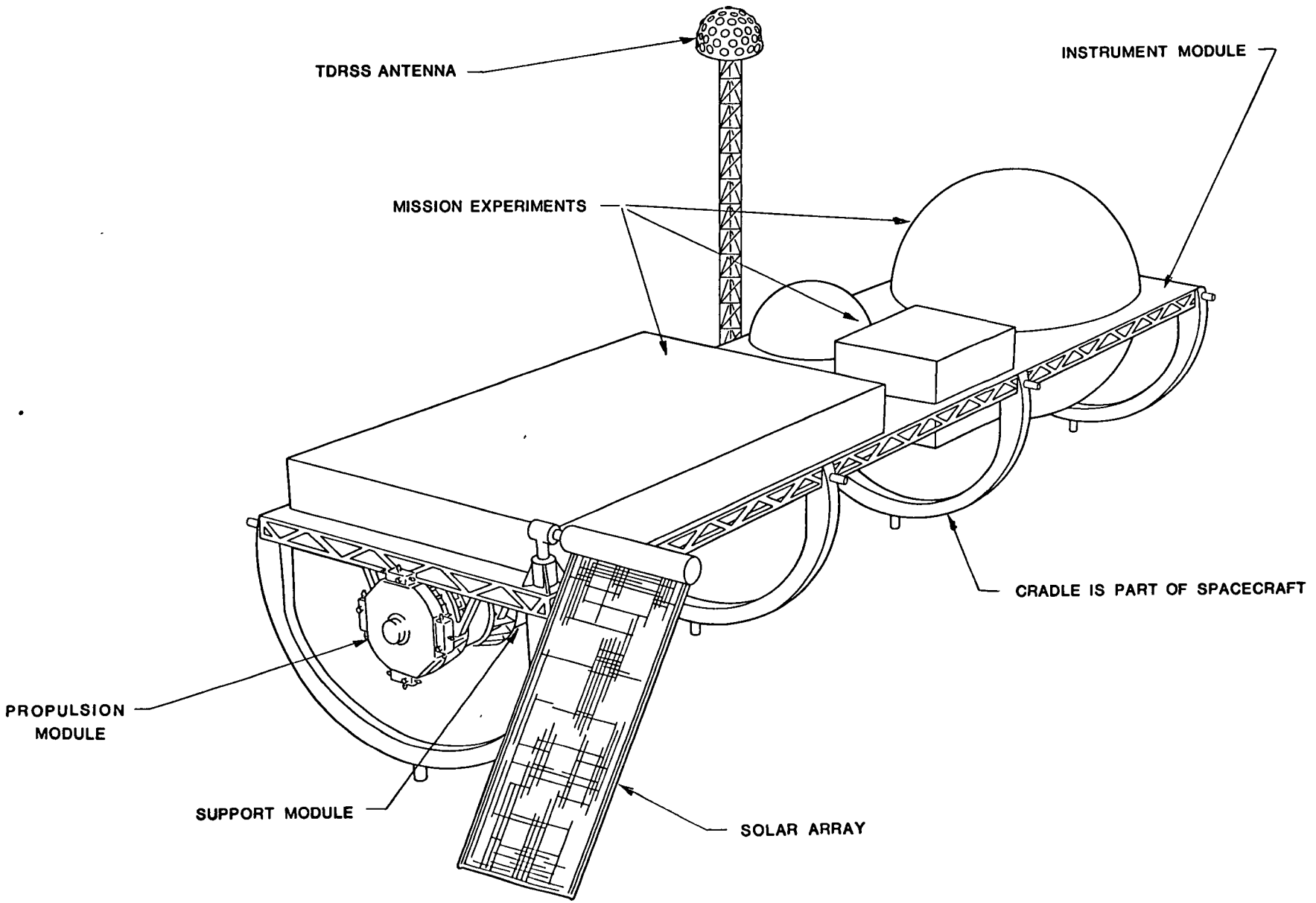


FIGURE 1. Cosmic Ray Observatory

will orient the spacecraft for optimum Sun exposure on the solar array. A momentum bias configuration will be used with hydrazine dumping.

Power Subsystem. The power subsystem is capable of controlling, storing, distributing, and monitoring power derived from the solar array.

Solar Array. The solar array will provide approximately 2 kW of power when normal to the Sun. The solar array will be a deployable solar array mounted to the instrument module.

Communications and Data Handling Subsystem (C&DH). The C&DH Subsystem provides a means for ground and on-board control of all spacecraft and instrument functions and for retrieval of spacecraft housekeeping and instrument data. The instrument data rate on the CRO is estimated to be 7 kbps. A NASA standard tape recorder or a bubble memory will be used to record data between TDRSS contacts. The recorded data will be played back concurrently with the real-time data. The combined data rate will be about 25 kbps, requiring a TDRSS Multiple Access link for one-third of each orbit, using a 10-W transmitter output.

Antennas. There are two spacecraft antennas. For normal operations, a Ball Aerospace 14-dB, electronically steered S-band antenna provides both forward and return links through the TDRSS. The antenna is a 76-cm hemisphere with 128 elements internally controlled to provide automatic search and tracking functions. The second antenna assembly is an omnidirectional antenna comprising a pair of hemispheric pattern antennas, providing a net gain of -3 dB for emergency communications through the TDRSS single-access antennas.

Propulsion Module. A propulsion module is required to provide the forces necessary for drag compensation and for unloading the momentum wheels. It will contain 1200 kg of hydrazine.

Ground Data Handling System

CRO will utilize existing facilities in the POCC and the Information Processing Division (IPD) at the GSFC to capture and store the spacecraft data and to generate the requisite data products for the science investigators.

DATA

The science data will be delivered in the form of data packets on magnetic tape. Each packet will contain both instrument and ancillary data, the latter including time, orbit elements, instrument orientation, and appropriate housekeeping data. All data will be in physical units and formatted and annotated for direct computer entry.

MISSION OPTIONS

A tentative science payload complement was used to define the mission described in this brochure. The actual payload would be defined by selection as a result of an Announcement of Opportunity. It is anticipated that a similar mission profile will evolve from a detailed study using the selected flight experiments.

An alternative to the CRO is a series of single experiments. These might be flown on several smaller spacecraft as described in another brochure: High Energy Astrophysics Explorers. Or they could be flown on a multi-discipline, space platform, if one were available. Cosmic ray experiments, in general, do not place severe demands on platform capabilities. The availability of a serviceable platform would also permit periodic interchange of instruments as part of a long-term evolutionary program in cosmic ray astrophysics.

PROGRAM ASSESSMENT

None of the payload experiments, described herein, pushes the current state of technology. It is anticipated that CRO could be launched approximately 4 years from the start of development.

TECHNOLOGY READINESS/TECHNOLOGY DEVELOPMENTS NEEDED

The technology required for the CRO instruments and bus is within the state of the art. Many, perhaps all, of the science instruments will initially fly on the Shuttle, thus permitting performance optimization as well as proof of hardware design. The support module functions will employ existing technology.